ERDC/CRREL TR-09-1

Cold Regions Research and Engineering Laboratory

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Laboratory Testing of Architectural Exterior Wall Fins

Leonard Zabilansky, William Burch, and Tommie Hall

January 2009

COVER: Initial condition of mock-up covered in snow and ice of varying thicknesses from 2.5 to 7 inches; ice retention devices are installed on the left side of the fin and the right side is used as the control.

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Final report

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Abstract: Ice and snow accumulation sliding from the exterior wall fins installed on the New Meadowlands Stadium in New Jersey, future home field for the New York Jets and New York Giants football teams, was recognized as a potential hazard to pedestrians. The objective of this test program was first to determine if the hazard existed with the standard fin and secondly to evaluate the performance of four ice retention devices (IRDs). A mock-up was assembled using four fins in a vertical stack with different angles. Four IRDs were tested: three were continuous strips and the fourth was a truncated cone attached to the fin at 12 inches on centers. The IRDs were mounted along the lower edge of the fin. To provide water drainage, all the IRDs were spaced off the fin using 3/16-inch plastic spacers. To assess the effectiveness of the IRDs under similar conditions, IRDs were only installed on the fins on the left side of the mock-up while the right side, or standard fin, was used as a control.

Testing confirmed that IRDs are needed to reduce the potential hazard of large sheets of snow and ice sliding off the fin. The continuous barriers are problematic because the drainage paths freeze and water travels to the end of the fin to form large ice columns or because water travels over the top of the barrier to form icicles with limited anchoring. The fourth option, the truncated cone, provides discrete anchoring for the accumulation and allows it to melt in place. The potential for large icicles to form still exists; when they present a hazard to pedestrians they should be physically removed.

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Preface

This report was prepared for Skanska USA Building Inc. headquartered in Parsippany, NJ, contractor for the New Meadowlands Stadium in New Jersey. The stadium, to be completed in 2010, will be the home field for the New York Giants and New York Jets—the first facility built specifically to accommodate two National Football League teams. The multipurpose stadium will also be used for concerts and other entertainment and sports activities.

The report was prepared under the general supervision of Dr. Thomas J. Tantillo, Chief, Engineering Resources Branch, Cold Regions Research and Engineering Laboratory (CRREL); Dr. Justin B. Berman, Chief, Research and Engineering Division, CRREL; Dr. Lance D. Hansen, Deputy Director, CRREL; and Dr. Robert E. Davis, Director, CRREL.

The Commander and Executive Director of the U.S. Army Engineer Research and Development Center is COL Gary E. Johnston. The Director is Dr. James R. Houston.

1 Introduction

Ice and snow accumulation sliding from the exterior wall fins installed on the New Meadowlands Stadium in New Jersey, future home field for the New York Jets and New York Giants football teams, was recognized as a potential hazard to pedestrians. The objective of this test program was first to determine if the hazard existed with the standard fin and secondly to evaluate the performance of four ice retention devices (IRDs). A mock-up was assembled using four fins in a vertical stack, in one of the following orientations: all four fins at a 30° angle from the horizontal; all four fins at 50° from the horizontal; or the top three fins at 30° and the bottom fin at 50° from the horizontal. Four IRDs were tested: three were continuous strips (options 1, 2, and 3) and the fourth was a truncated cone attached to the fin at 12 inches on centers (option 4). The IRDs were mounted along the lower edge of the fin. To provide water drainage, all the IRDs were spaced off the fin using 3/16-inch plastic spacers. To assess the effectiveness of the IRDs under similar conditions, IRDs were only installed on the fins on the left side of the mock-up while the right side, or standard fin, was used as a control.

The mock-up was subjected to five tests using ice, snow, or snow/ice accumulations. Icing of the model was done by successively spraying the mock-up with water and allowing it to freeze before applying the next layer. The snow cover was generated using a commercially available snow gun while the room temperature was below 23°F. For the snow/ice accumulation, the initial layer of dry snow was covered with saturated snow and the excess water saturated the initial layer of snow. Once the required accumulation was achieved, the refrigeration units were defrosted and the room was cooled to freeze any available water and stabilize the accumulation. Before testing, a narrow strip of the fin was deiced to assure that the ice shedding processes on the left and right side of the fins were independent. The mock-up was subjected to wind (23 mph), localized heating, or warming room temperatures while the melting/shedding process was documented.

In the first test, it was apparent that IRDs were required because roughly two-thirds of the accumulation on the standard (or control) fin slid off as

a single piece. This initial observation was reinforced with every subsequent test. The limitations of the continuous barriers (options 1, 2, and 3) were also apparent as the drainage paths under these barriers froze. With the drainage blocked, the upper side of the barriers served as a "gutter" conveying the water to the end of the barrier and forming icicles at the end of the fins. In the prototype, the IRDs are the full length of the fin; therefore potentially double the amount of water will be redirected to the end of the fin. The volume of water redirected may triple because the stadium has up to 12 fins in a stack compared to four in the mock-up. In the extreme case, melt water off adjacent fins could form a column of ice in the narrow gap between adjacent stacks of fins. Taking the scenario one more step, the "gutter" would eventually fill with ice and water would flow over the barrier, forming icicles along the leading edge of the fin and below the IRD. The anchoring for these icicles could be limited because ice on the top edge of the IRD could melt, disconnecting the icicles from the retained accumulation.

Buttons (IRD option 4) are very simple, but also very effective in retaining the accumulation. The discrete buttons allow the melt water to cascade from fin to fin in the stack. The accumulation encapsulates the buttons, which anchors the ice and snow in place. Spacing under the button provides additional mechanical locking of the accumulation to the buttons. The panel joint along the leading edge of the fin provides an additional anchoring point for the icicles. Snow and ice will slide between the buttons, but the size of the pieces is controlled by the 12-inch spacing of the buttons and the limited strength of the ice or snow to cantilever over the edge before it breaks off.

In summary, IRDs need to be installed on the fin to reduce the potential for hazards to pedestrians. The continuous barriers (IRD options 1, 2, and 3) are problematic because the drainage paths freeze and water travels to the end of the fin to form large ice columns or because water travels over the top of the barrier to form icicles with limited anchoring. IRD option 4 provides discrete anchoring for the accumulation and allows it to melt in place. The potential for large icicles to form still exists; when they present a hazard to pedestrians they should be physically removed.

2 Laboratory Test Procedure

A full-scale architectural exterior wall fin mock-up of the completed stadium was subjected to snow and ice shedding tests at the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH. The objective of the tests was twofold, first to establish the need for ice retention devices and secondly to evaluate four different ice retention devices.

The mock-up was assembled using four fins 13.6-feet long, vertically stacked in one of the five configurations shown in Figures 1–5, respectively.

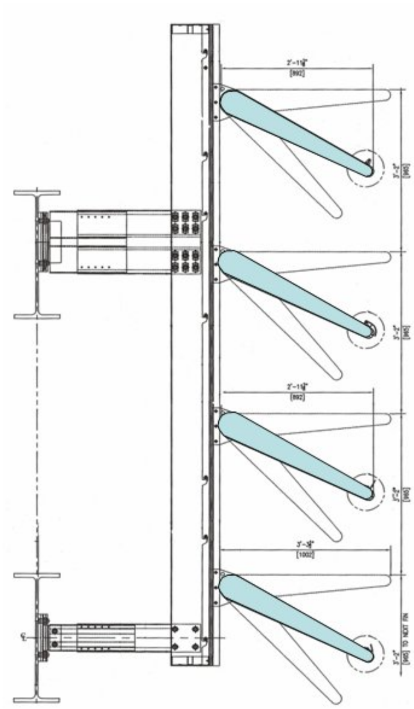

Figure 1. All fins at 30° angle from horizontal with ice retention devices installed (configuration 1).

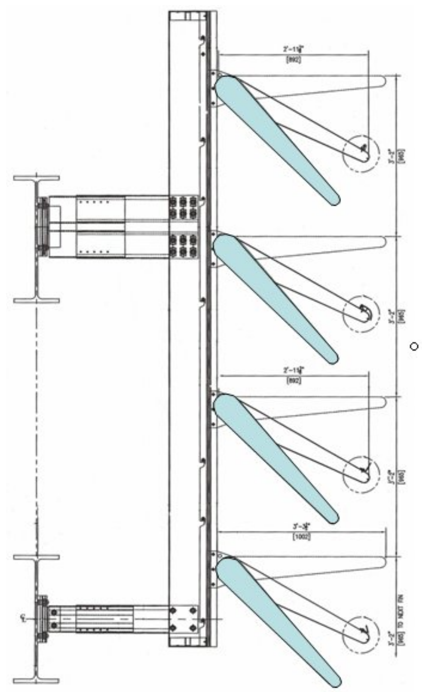

Figure 2. All fins at 50° from horizontal with ice retention devices installed (configuration 2).

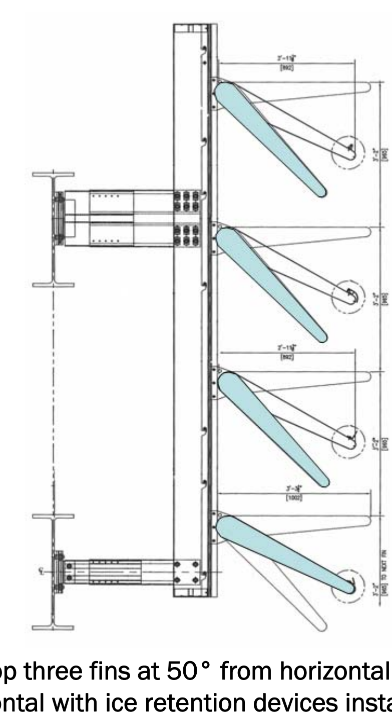

Figure 3. Top three fins at 50° from horizontal and bottom fin at 30° from horizontal with ice retention devices installed (configuration 3).

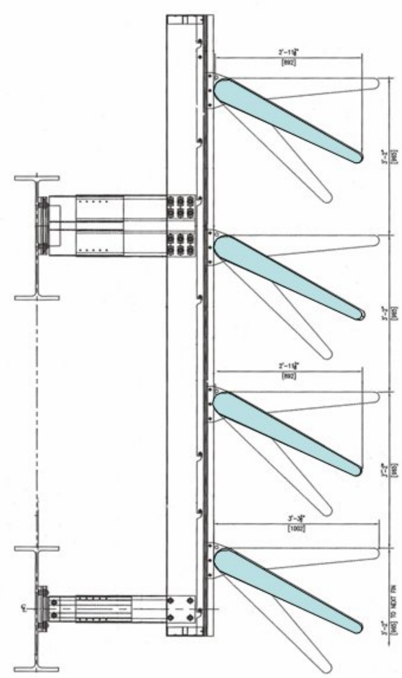

Figure 4. All fins at 30° from horizontal without ice retention device (configuration 4).

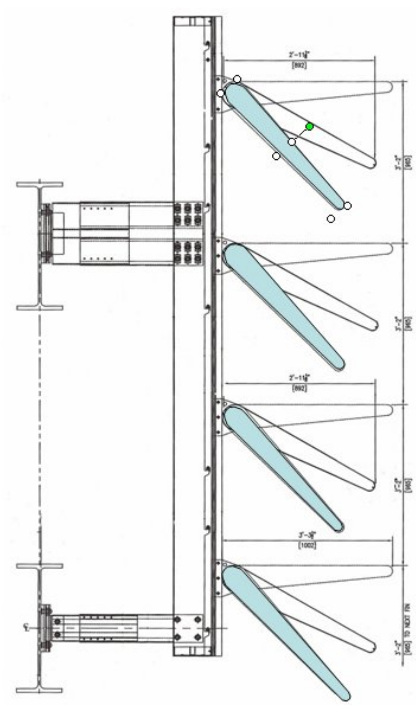

Figure 5. All fins at 50° from horizontal without ice retention device (configuration 5).

The fins used to assemble the mock-up were new and the surfaces were not exposed to weathering. The change in the adhesion strength of the ice to the fin due to weathering was not considered in this study.

Details of the four IRDs evaluated to retain the ice and snow accumulations are shown in Figures 6–9.

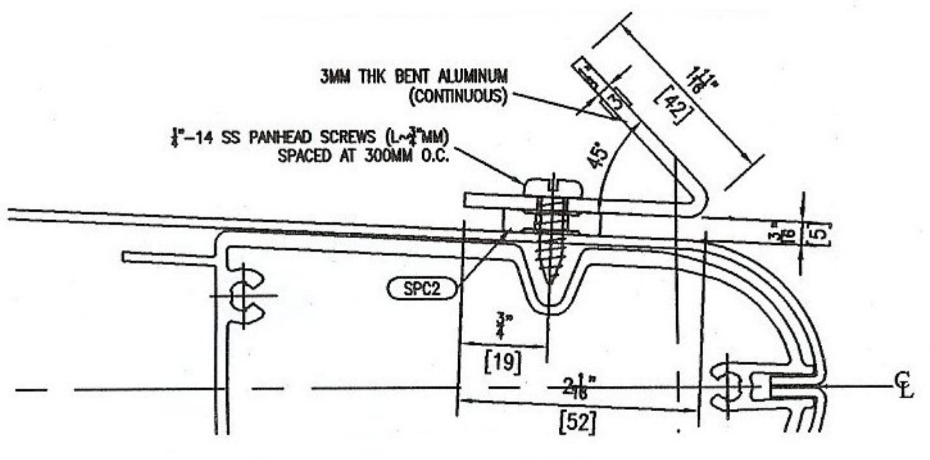

Figure 6. IRD option 1.

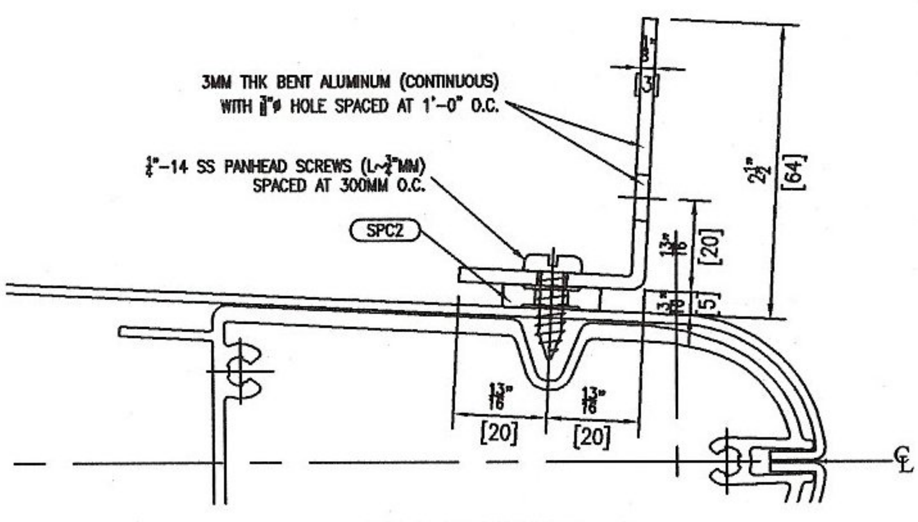

Figure 7. IRD option 2.

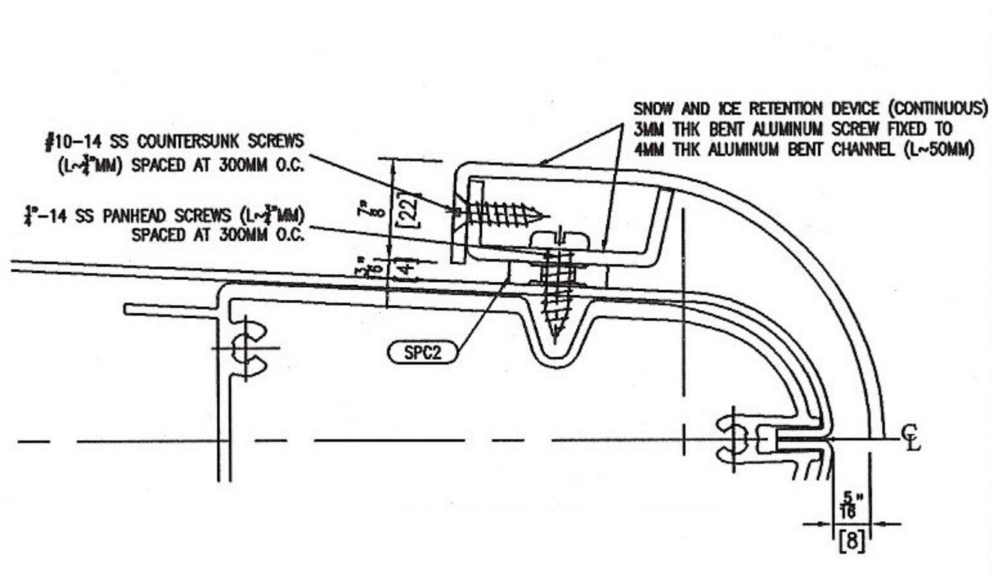

Figure 8. IRD option 3.

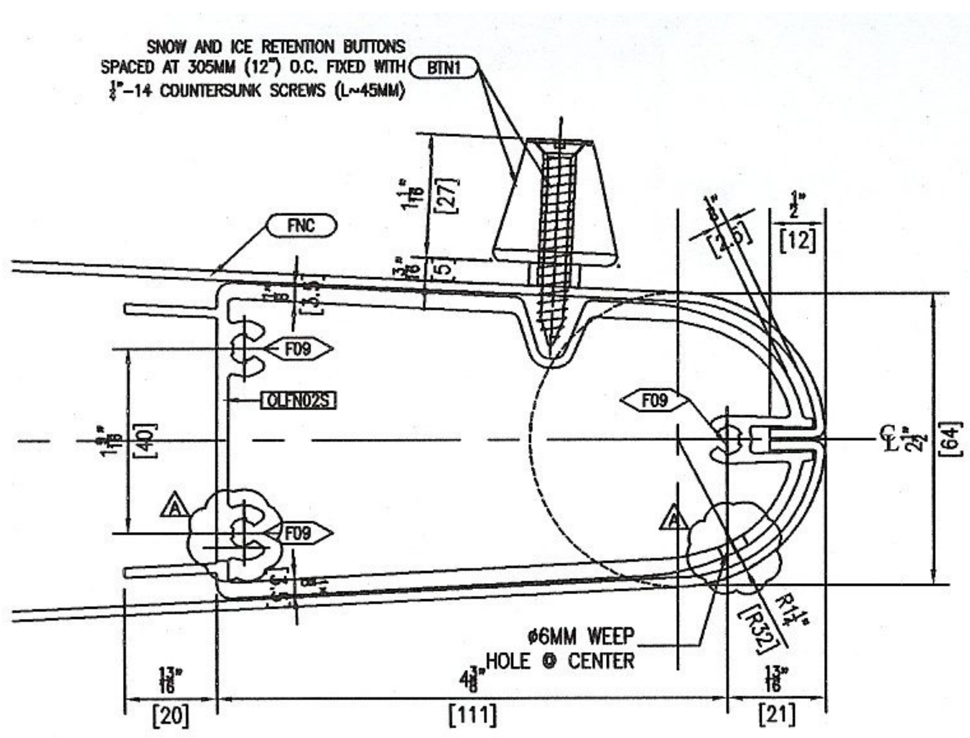

Figure 9. IRD option 4.

Fin designation

The IRDs were installed on the left side of the fin, with the fin designation "A" as the first character in the fin identifier. To allow for direct comparison between the modified and the standard, or control, fin under similar icing and snow conditions, the IRDs were not installed on the right or "B" side of the fins. Similar to the right side, the standard (control) fins have a "B" as the first character in the fin identifier. The factory-drilled attachment holes on the B side were covered with 1-inch-diameter disc made from foil tape to prevent mechanical attachment of the accumulation. Fins are numbered starting at the bottom and progressing to the top. The fin layouts for the first few tests are listed in Table 1.

Table 1. Fin designation.

Fin	A side	B side
4 (top)	A4 IRD option 4	B4 Standard/Control
3	A3 IRD option 3	B3 Standard/Control
2	A2 IRD option 2	B2 Standard/Control
1 (bottom)	A1 IRD option 1	B1 Standard/Control

Test procedure

The fin wall mock-up was tested in the Materials Evaluation Facility (MEF) at CRREL. Ambient temperature was maintained below freezing while the fins were subjected to either icing or snow conditions. The model was iced by successively wetting the fins' surface with misting nozzles on a garden hose as shown in Figure 10. A commercially available snow gun adapted with an articulating wand was used to cover the model with snow. A low-velocity fan was used to create a light wind in the room to assure the snow was evenly distributed near the structure (Figure 11). Once the desired layer of ice or snow accumulated on the fins, the refrigeration air units were defrosted to recover cooling efficiency. With the air units defrosted, the room temperature was cooled to stabilize the accumulation before starting the test sequence.

Figure 10. Icing of the model with a spray nozzle on a garden hose.

Figure 11. Snowmaking using a commercially available snow gun with an articulating head. A low-velocity fan is used to provide even distribution of the snow.

To assure that the ice shedding process on the A and B sides of the fins were independent, a narrow strip on the vertical centerline of the fin was deiced before starting the test procedure. A hot iron as shown in Figure 12 was used to melt the ice or snow to minimize the area affected by the deicing procedure.

Figure 12. Deicing a vertical slot to isolate the modified side ("A") from the control side ("B").

3 Observations

Test protocol is outlined in Table 2, and the details and observations for Tests 1–5 appear as Appendixes A–E, respectively. Observations from the five tests can be grouped as shedding, performance of continuous ice retention devices, and discrete ice retention.

Table 2. Test sequence.

Test 1	Configurations 2 and 5.
	1/4-inch layer of ice.
	Increase room temperature to shed the ice with wind (23 mph).
Test 2	Configurations 2 and 5.
	3 inches of snow.
	Increase room temperature to shed accumulation.
Test 3	Configuration 3.
	Heavy snow and snow/ice varying from 2 inches on the edges to 6 inches in the center of the fins.
	Increase room temperature to shed accumulation.
Test 4	Configurations 1 and 4 with modified IRD options 2a and 2b installed on fins B2 and B3, respectively.
	3/8- to 1/2-inch icing.
	Increase room temperature to shed accumulation.
Test 5	Configurations 1 and 4 with IRD option 4 installed on the “A” side of all the fins. No IRDs on the “B” side.
	1/2-inch icing of model.
	Cycle radiant heated on fins A3 and A4 shield fins A1 and A2 from radiate heat for icicle formation. Radiant heater on for several hours with room cold. Increase ambient temperature following the weekend of below freezing.

Shedding

The thin metal skin used to fabricate the fins is a better heat conductor than the ice or snow. As the temperature increased in the testing phase, the bond between the fin and the accumulation melted before the accumulation melted. The melt water sandwiched between the fin and the accumulation allowed the accumulation to slide on the fin. Suction by a thin layer of water resisted the gravitational force, sliding the accumulation off the fin. As the suction pressure was released, the accumulation slid down the fin. The accumulation had more thermal inertia than the fins and

was slower responding to the temperature rise; consequently there was no real loss in structural integrity of the ice or snow. With no real loss in strength, the accumulation could cantilever off the edge of the fin, in some instances up to 18 inches, before breaking (Figure 13). The size of the snow blocks picked up off the floor were large enough to seriously injure a pedestrian (Figure 14).

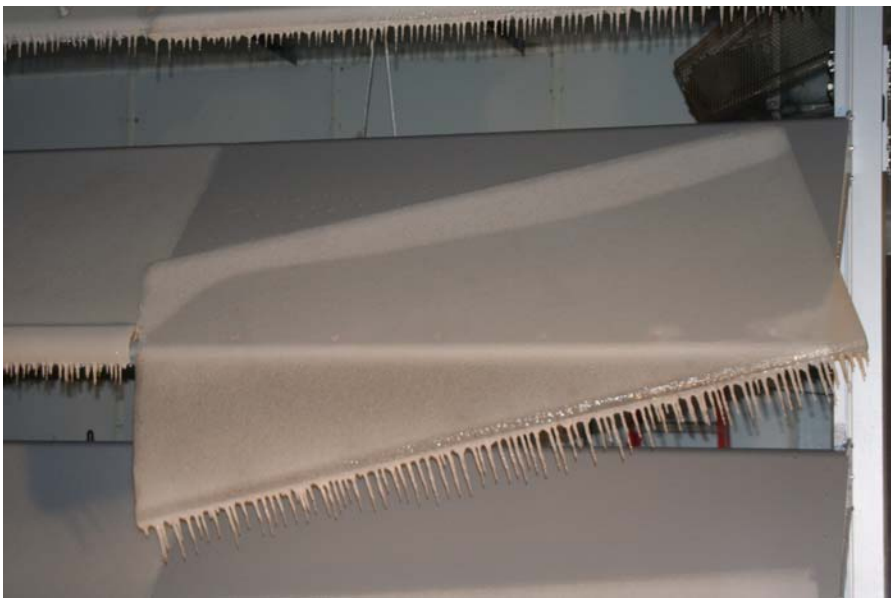

Figure 13. Ice cantilevered off the fin before breaking off as a large section.

Continuous IRDs

The continuous IRD options 1, 2, and 3 are problematic especially in icing conditions. The device is mounted along the lower edge of the fin and spaced off the fin 3/16 of an inch to allow water to drain under the IRD. In icing conditions, water freezes under the IRD and blocks the drainage paths. Water draining off the fin is redirected to the end of the fin. Ice forming in the trough between the fin and the top edge of IRD options 1, 2, and 3 is shown in Figures 15, 16, and 17, respectively.

Figure 14. Piece of snow that fell off standard fin without the IRDs.

Figure 15. IRD option 1; with a frozen drainage path, the water is diverted to the end of the fin.

Figure 16. Similar to IRD option 1 shown in Figure 15, when the drainage path is frozen, the water is diverted to the end of the fin potentially forming a column of ice between adjacent fin stacks.

The underside of fin A3 during an icing and snow test is shown in Figures 18 and 19, respectively. Icicles on the fin in Figure 18 indicate that water passed under the IRD before the drainage path froze. In contrast, the accumulated snow impedes the flow of water under the IRD, which freezes and blocks the drainage when saturated with water. The curved front face of the IRD does not provide any mechanical lock for the icicles, and it is conceivable that the warm air could melt the ice bond from the underside, leaving the icicles with limited attachment. Any wind could easily break the icicles free.

Figure 17. Top side of IRD option 3 showing the blocked drainage paths similar to IRD options 1 and 2.

Figure 18. Underside of fin A3 during icing tests.

Figure 19. Underside of fin A3 during snow test.

Recognizing that plugging the drainage path under the continuous IRDs affected their performance, modifications were made to IRD option 2 to assess whether better drainage would improve the performance. Additional 3/8-inch holes were drilled in the upright leg of IRD option 2 to decrease the spacing from 12 inches on center to 3 inches on center. This modification shown in Figure 20 is referenced as IRD 2a. Slots 1/2-inch wide by 2-inch long at 3 inches on center were milled into the upright leg of the angle. The modified IRD is shown in Figure 21 and is referred to as IRD 2b.

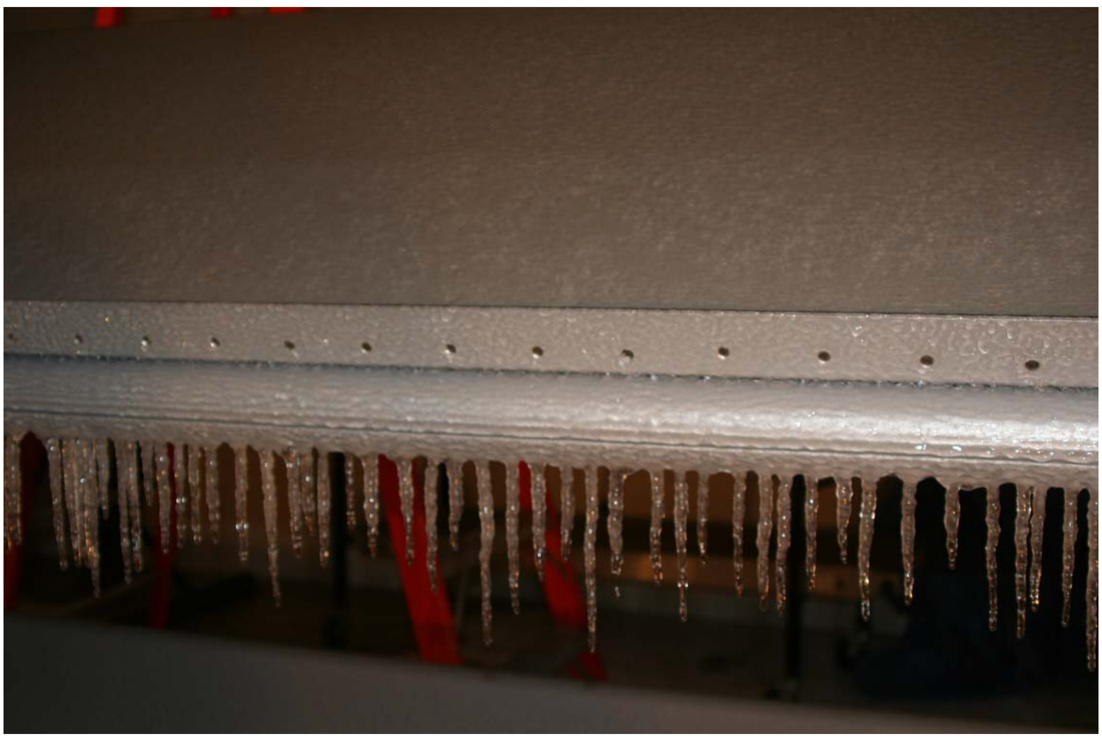

Figure 20. IRD option 2 modified by decreasing the 3/8-inch hole spacing to 3 inches (IRD 2a). Icing conditions after 40 minutes of icing.

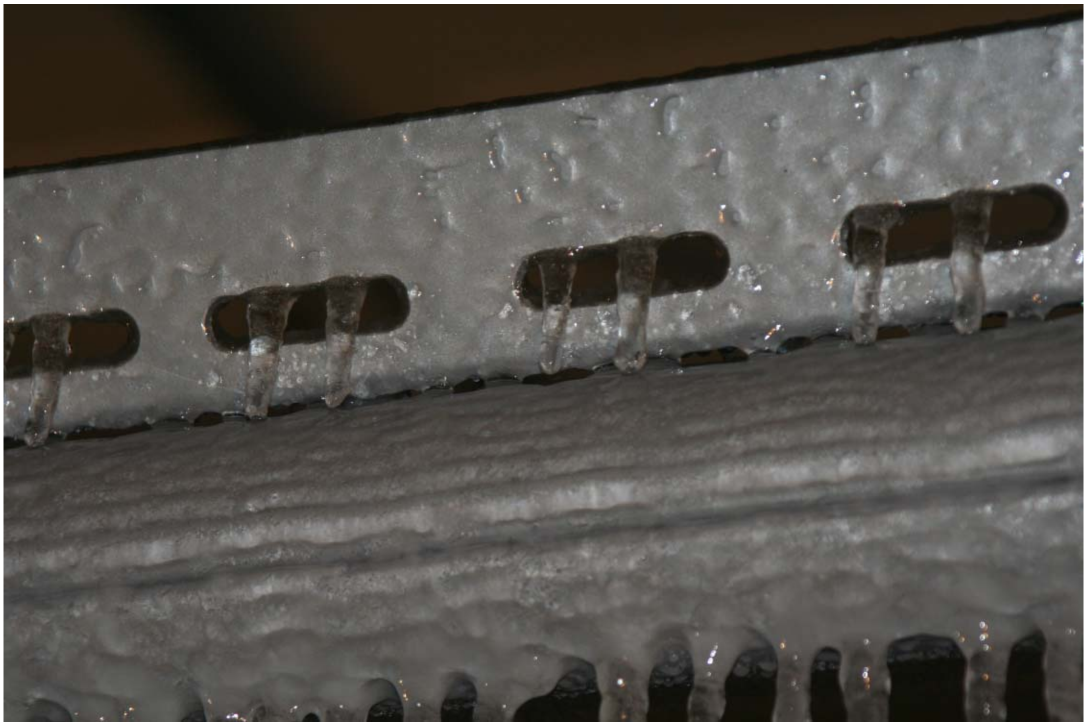

Figure 21. IRD option 2 with 1/2- by 2-inch-long slots 3 inches on center (IRD 2b). Icing conditions after 40 minutes of icing.

Although the drainage holes were significantly increased, they eventually plugged with ice (Figures 22 and 23) and the water was diverted to the end of the fin (Figure 24). It was concluded that the continuous barriers were not a viable IRD because the melt water was diverted to the end of the fin. Until the trough formed by the fin and the upper edge of the IRD was filled with ice, water would be diverted to the end of the fin. Collectively, the water from the adjacent stacks of fins could form a column of ice in the gap between the fins, presenting a new hazard. Once the ice was above the top edge of the IRD, water would flow over the IRD and form icicles on the leading edge of the fin. Icicles were attached to the fin by the adhesion and mechanical locking with the panel seam on the front edge of the fin. Solar heating could melt the surface adhesion, leaving just the limited strength of the mechanical locking with the panel joint to hold the icicles (Figure 25).

Figure 22. Top view of IRD 2a after 90 minutes of icing; the holes are iced over.

Figure 23. Lower edge of IRD 2b after 90 minutes of icing; although the slots are still open, they will eventually plug.

Figure 24. End view of fin 3b with IRD 2a in the foreground and IRD option 2 in the background. Drain paths and holes in the upright leg are frozen and the water is diverted to the end of the fin.

Figure 25. Mechanical locking of the icicles by the panel joint on the leading edge of the fin.

Discrete IRD

IRD option 4 is a button consisting of a truncated cone that is 1 1/16-inch high and spaced off the fin 3/16 of an inch as shown in Figure 26. They are attached at 12 inches on center. The snow or ice accumulation encapsulated the IRD, and the mechanical locking retained the accumulation (Figure 27). The discrete approach avoids the problem of the IRD interfering with the free flow of melt water cascading down the stack of fins, unlike the continuous IRDs that divert the water to the end of the fin. Icing of any significant thickness has enough structural integrity to arch between the buttons or be trapped by the gap under the button if the ice begins to slide. A snow accumulation that is melting and sliding may not have the structural integrity to arch between the buttons, but may be sheared into 12-inch-wide strips as shown in Figure 28. If the snow is weak enough to be sheared by the buttons, it will not have the structural integrity to cantilever off the fin before the unsupported segment breaks off.

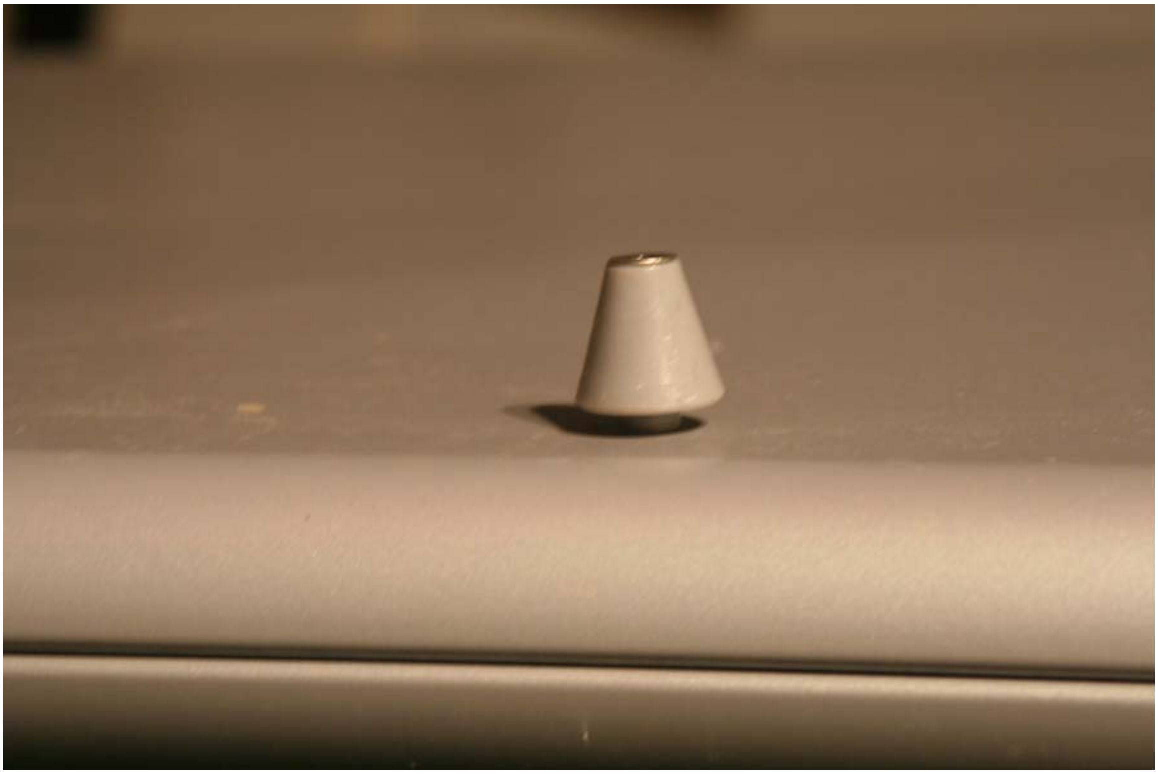

Figure 26. Buttons (IRD option 4) are attached to the fin at 12 inches on center.

Figure 27. IRD option 4. The buttons 12 inches on center are encapsulated in ice and retain the sheet of ice (left), while the ice slides off without the IRD (right).

Figure 28. Separating the snow accumulation from the IRD to assess the size of the snow pieces falling off the fin.

IRD option 4 is a very simple device that is effective in stabilizing the accumulation without the limitations of the continuous IRDs. The consensus of the test team was that the buttons were the best alternative for retaining the ice. For the last test, the buttons were installed on the fins on the A side. The B side of the fin was the standard, or control, fin without any IRDs. The mock-up was covered in ice, varying in thickness from 3/8 to 1/2 inch. The initial conditions are shown in Figure 29 as the slot between the A and B sides is being deiced.

The ramification of a heat source on the upper fins (e.g., an exhaust fan or solar heat) that melted the accumulation—with the melt water refreezing on the lower fins—was assessed in Test 5. Radiant heaters were used to heat the upper fins (A3 and A4) while the lower fins (A1 and A2) were shaded (Figure 30); the room was approximately 23°F. In the first phase, the heaters were cycled on until the water started dripping off the fins (approximately 15 minutes) then shut off to allow the melt water to refreeze (approximately 10 minutes). Seven cycles were conducted with melting on the upper fins and refreezing of the water on the shaded fins. In the second phase of testing, the heaters were moved away from the fins with the heaters on continuously for the next 6 hours while the room temperature was

Figure 29. Initial condition for Test 5 with IRD option 4 installed on the A side of the fin. The B side is the standard, or control, fin.

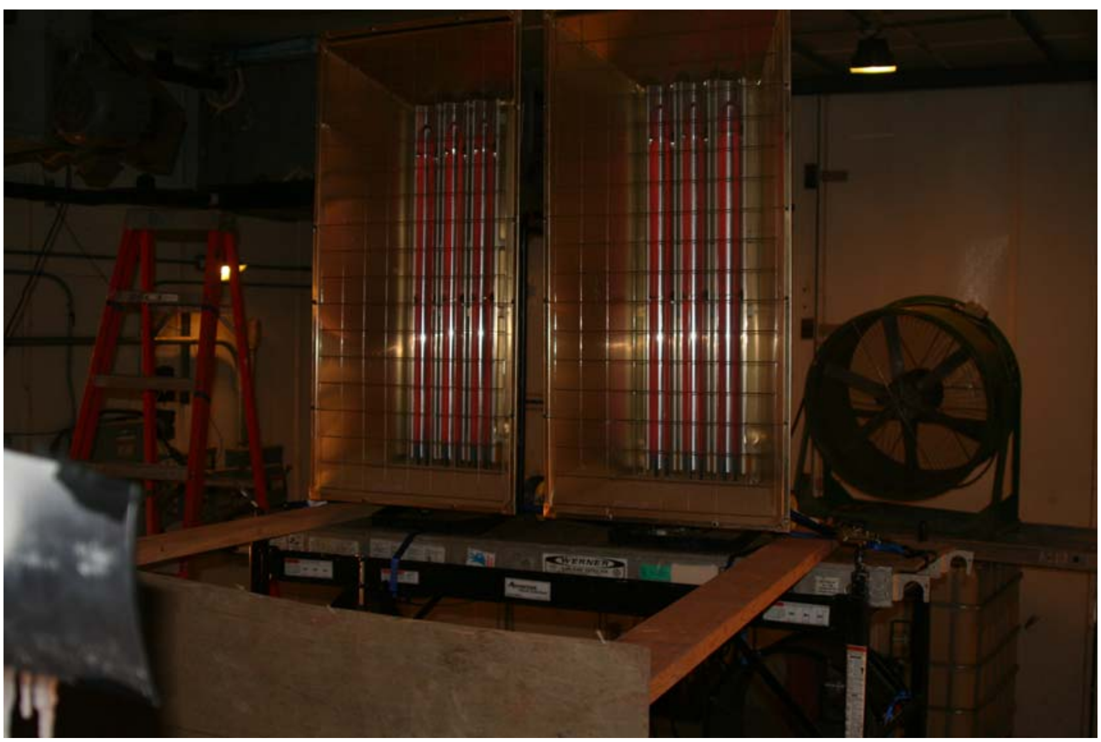

Figure 30. Using radiant heaters to simulate solar heating of the top fins (A3 and A4) while the bottom fins (A1 and A2) are shaded by the plywood.

maintained at 23°F. Ice conditions at the conclusion of phase 2 are shown in Figure 31. For phase 3, the refrigeration system was shut off and the ambient temperature was allowed to increase. A similar procedure was used in the previous tests. As in the previous test, the ice on the B side slid off as a sheet, while the ice on the A side melted in place. As shown in Figure 31, icicles will form and if they present a potential hazard they will have to be physically removed.

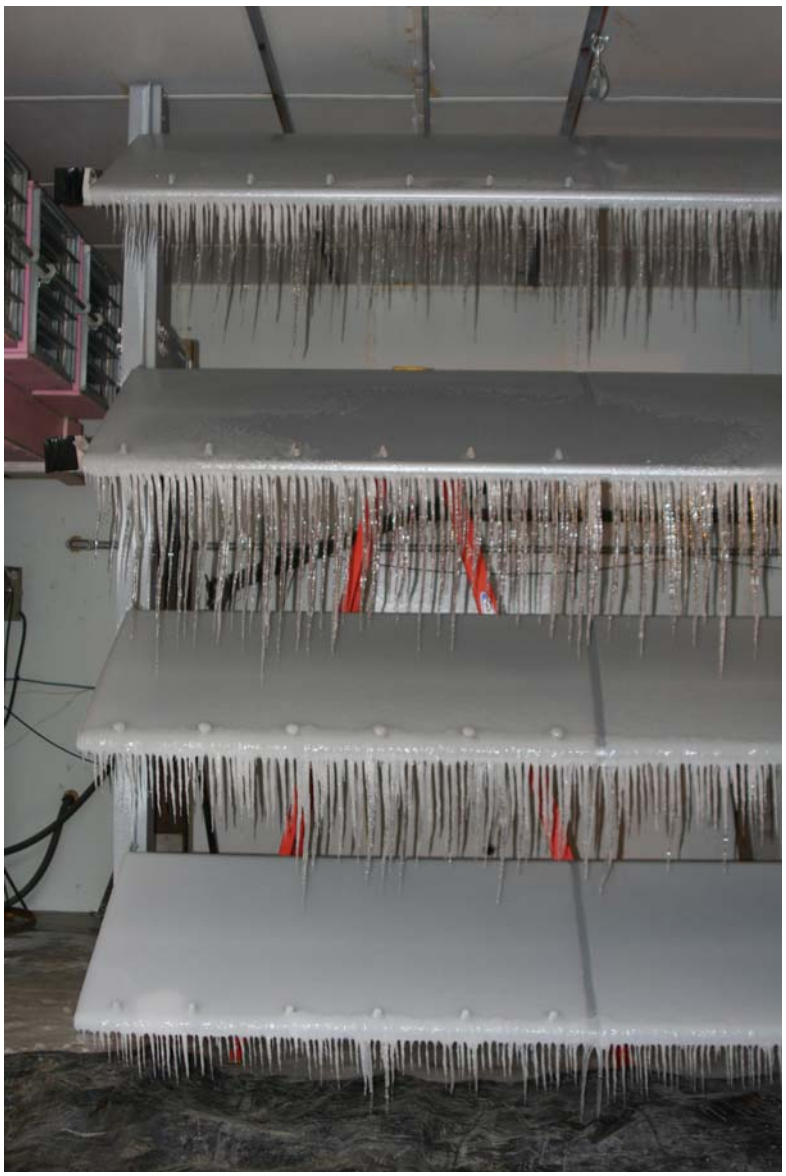

Figure 31. Icing conditions at the conclusion of heating fins A3 and A4 with radiant heaters while shading fins A1 and A2. The room temperature was approximately 23°F, and the melt water refroze on the lower panels.

4 Recommendations

Ice and snow accumulations slide off the standard fins as a large mass, and the pieces are large enough to injure a pedestrian. The accumulations have to be retained to allow the ice or snow to melt in place. The continuous ice retention devices are very problematic in that the drainage paths freeze, diverting water to the end of the fin or over the top of the IRD, resulting in poorly anchored icicles. Based on these tests, the recommended ice retention device is option 4—the truncated cones spaced 12 inches on center. This discrete IRD is simple and effective in retaining ice and snow accumulations and allowing them to melt in place. As the accumulation melts, the structural integrity of the accumulation decreases and the IRD splits the sliding accumulation into strips less than 12 inches wide, with the length dictated by the limited bending strength of the ice or snow. The discrete IRD does not prevent the formation of icicles and the fins need to be monitored; if a potential hazard exists, it will have to be physically removed.

Appendix A: Test 1

Issue date: May 19, 2008

Project title and number: Evaluation of Sun Control Fins in Snow and Icing Conditions

Testing agency name and address: Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755

Name of test personnel: William Burch, Tommie Hall, and Len Zabilansky

Date of testing: May 12, 2008

Significant meteorological conditions: Mock-up was covered with approximately 1/4 inch of freezing rain formed by misting the model at 2°F for approximately 1 hour. Before testing, a slot between side A and B was deiced to insure independent ice shedding processes.

Report number: Test 1

Mock-up test number: Configuration 2 was on the left (A side) of the mock-up, with ice retention device (IRD) option 1, IRD option 2, IRD option 3, and IRD option 4 on fins A1, A2, A3, and A4, respectively; fin A1 was on the bottom. Configuration 5 was used on the right (B side) with no IRD installed.

Procedure: The mock-up was covered in 1/4-inch ice by misting water on the mock-up with the ambient temperature of 0°F. The surface was allowed to freeze before the model was sprayed again. Temperature of the ice was allowed to stabilize before proceeding to the ice shedding phase of the test.

The test started when the refrigeration system was set to 35°F and room temperature increased by opening access doors. A fan was used to circulate the air to insure uniform room temperature. Before testing, a hot iron was used to deice a narrow section of the fin on the vertical centerline of

all fins to separate the A (left) side with the IRDs from the B (right) side that was used as the control. This prevented interaction between the test sections with similar icing conditions.

Observations regarding compliance with contract documents:

1. Ice on the control fins (B side) slid off in large sheets.
2. All the continuous IRDs (i.e., options 1, 2, and 3) were spaced off the fin with 3/16-inch-thick plastic washers at each mounting screw. With the fins unheated, the spray water froze and blocked the drainage paths. The continuous barrier along the bottom of the fin served as a gutter, conveying the water to the end of the barrier strip before it dripped to the next fin.
3. IRD option 4 at 12 inches on center did not impede the melt water, allowing it to cascade to the lower fin.
4. All the IRDs retained the ice.

Photography from the testing

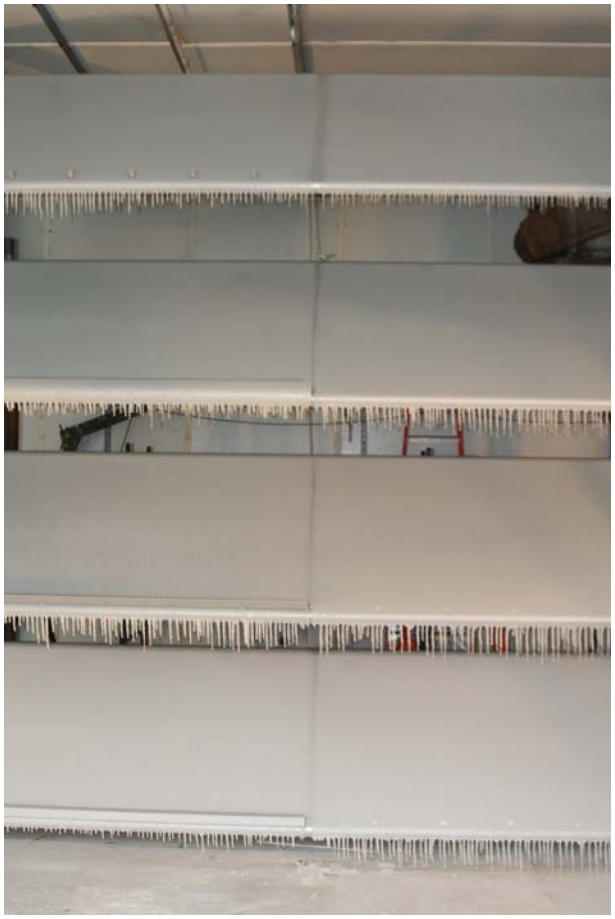

Figure 1.1. Initial conditions of fins with the vertical centerline deiced. The ice retention devices are installed on the A (left) side of the fins. The B (right) side is used as the control. IRD options 1, 2, 3, and 4 are installed on the A side of the fins, starting with option 1 on the bottom fin (A1) and progressing to option 4 installed on the top fin (A4).

Figure 1.2. Fin A1 with IRD option 1 installed. Note the drainage paths are blocked with ice and the continuous IRD serves as a gutter.

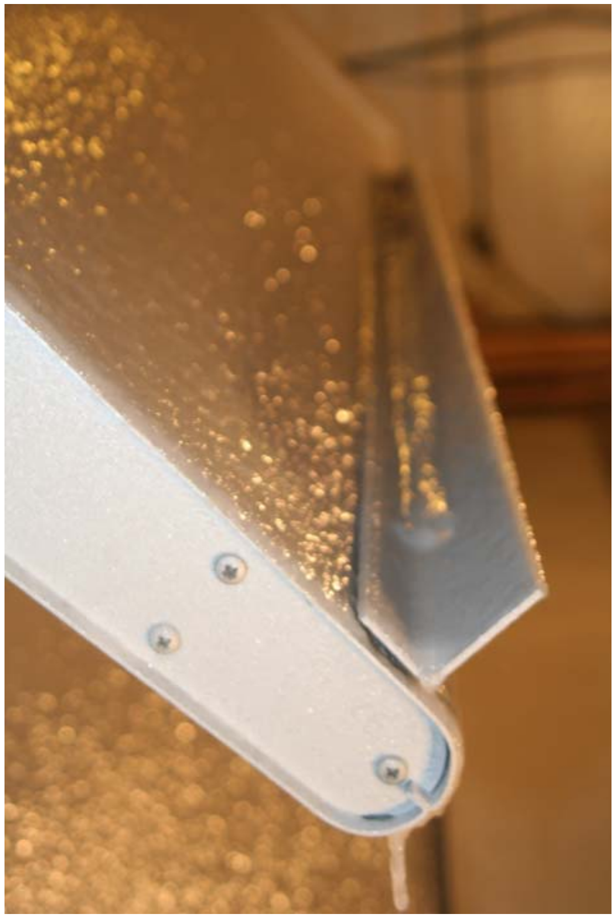

Figure 1.3. Fin A2 with IRD option 2 installed; the drainage paths are blocked with ice and the top edge of the IRD serves as a gutter.

Figure 1.4. Fin A3 with IRD option 3 installed; the drainage paths are blocked with ice similar to Figures 1.2 and 1.3.

Figure 1.5. Leading edge of the fin A3 with IRD option 3 installed with the drainage paths blocked with ice as shown in Figure 1.4; water is running over the top and freezing.

Figure 1.6. The icicles indicate two drainage paths on fin A3, over the front face and between the fin and the back side of IRD option. Capillary action may influence the location of the drips on the fin itself.

Figure 1.7. Removing the securely anchored icicles from the gap between the fin and IRD option 3 on fin A3 as the ice is melting.

Figure 1.8. A large fan was used to generate wind loading on ice. The fan was located on the vertical centerline of the fins with the discharge directed at one of the fins. A Young anemometer was used to measure the wind speed during the test; for this test the average wind speed was 23 mph.

Figure 1.9. The ice sheet starts to slide off fin B1.

Figure 1.10. The ice sheet continues to slide off fin B1, photograph taken 3 minutes after Figure 1.9 above.

Figure 1.11. The ice sheet sliding off fin B1, 5 minutes after the photograph in Figure 1.9.

Figure 1.12. Piece of ice from fin B1.

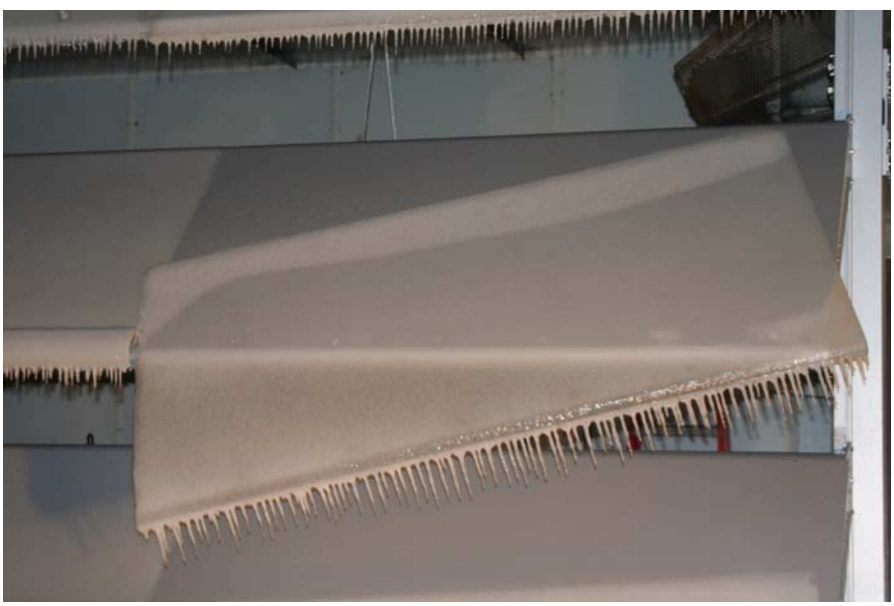

Figure 1.13. Ice is cantilevered approximately 15 inches off the left side of fin B4.

Figure 1.14. Manually removing the ice above the IRD on fin A4 is a very labor-intensive process.

Description of testing procedures and results yielded:

1. The drainage paths on all the continuous IRDs (i.e., options 1, 2 and 3) froze and the top edge of the barrier served as a gutter conveying the water to the end of the IRD. This has the potential of forming large icicles at the ends of the fins.
2. The ice slid off the control fins (B side) in large sheets.
3. IRD options 1, 2, and 3 retained the ice, but could result in large icicles due to the blocked drainage paths.
4. IRD option 4 anchored the ice and then allowed the ice to melt in place.

Modifications: No changes were made to the fins or the IRDs.

Appendix B: Test 2

Issue date: May 19, 2008

Project title and number: Evaluation of Sun Control Fins in Snow and Icing Conditions

Testing agency name and address: Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755

Name of test personnel: William Burch, Tommie Hall, and Len Zabilansky

Date of testing: May 13, 2008

Significant meteorological conditions: Mock-up was covered with approximately 3 inches of snow. Before testing, a slot between the A and B sides was deiced to insure that the ice shedding processes were independent.

Report number: Test 2

Mock-up test number: Configuration 2 was on the A (left) side of the mock-up, with ice retention device (IRD) option 1, IRD option 2, IRD option 3, and IRD option 4 on fins A1, A2, A3, and A4, respectively; fin A1 was on the bottom. The B (right) side of the mock-up was set to configuration 5 and used as a control, with no IRD installed.

Procedure: The mock-up was covered with a relatively uniform layer of 3 inches of snow using an articulated snow gun. The mast of the gun was periodically repositioned to achieve a uniform layer of snow. Snow started out dry and as the room temperature warmed up, the moisture content in the snow increased. A fan provided air currents to assure a uniform air temperature and snow distribution during the snowmaking process. At the completion of the snowmaking operation, the refrigeration air units were defrosted and the room cooled to 3°F. Room temperature was maintained overnight to stabilize the saturated snow before testing on Tuesday morning.

Tuesday morning the room was increased to 35°F and the snow on the vertical centerline of the fins was deiced to separate the A side from the B side. Once water started dripping, the fins were subjected to wind from the large fan.

Observations regarding compliance with contract documents:

1. Ice on the control fin (B side) slid off in large sheets.
2. All the IRDs retained the snow in place.
3. IRD 4 at 12 inches on center did not impede the melt water, allowing it to cascade to the lower panel.

Photography from the testing

Figure 2.1. The initial condition of the top fins with the vertical centerline deiced. IRD option 4 is installed on the left side the top fin (A4), and the right side (B4) is used as the control. IRD option 3 is mounted on the left side of the lower fin in the photograph (A3) while the right side (B3) is used as a control.

Figure 2.2. Underside of fin 3 with the ice sliding off the near side (B3) and while the ice is retained by IRD option 3 installed on the far side. The drainage path under IRD option 3 appears to be open on the bottom.

Figure 2.3. Snow is sliding off in mass on the right side of the fin (B3) while being retained by IRD option 3 on the left side (A3).

Figure 2.4. Fins on the A side of the mock-up are subjected to wind. Note that the snow slides off the fins on the B side of the mock-up.

Figure 2.5. Testing the effectiveness of IRD option 4 by separating the snow from the IRDs.

Figure 2.6. Snow can slide between IRD option 4, confirming that the IRD retains the snow.

Figure 2.7. Sliding snow engages with IRD option 4 on fin A4. The width of snow pieces falling from A4 should be controlled by the spacing of IRD option 4 and the length of the pieces, limited by the bending strength of the snow cantilevering off the fin.

Description of testing procedures and results yielded:

1. The snow freely slid off the control fins. The size of the blocks was dictated by the strength of the snow to cantilever off the edge of the fin and gravity.
2. Wind currents did not lift the snow off the fin.
3. All the IRDs retained the snow on the A side fins.

Modifications: No changes were made to the fins or the IRDs.

Appendix C: Test 3

Issue date: May 23, 2008

Project title and number: Evaluation of Sun Control Fins in Snow and Icing Conditions

Testing agency name and address: Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755

Name of test personnel: William Burch, Tommie Hall, and Len Zabilansky

Date of testing: May 14, 2008

Significant meteorological conditions: Mock-up was covered with wet snow and ice varying in depth from 2.5 to 7 inches. Before testing, a slot between side A and B was deiced to insure an independent ice shedding process.

Report number: Test 3

Mock-up test number: Configuration 3 was on the A (left) side of mock-up with ice retention device (IRD) option 1, IRD option 2, IRD option 3, and IRD option 4 on fins A1, A2, A3, and A4, respectively; fin A1 was on the bottom. The B (right) side was also set to configuration 3 and was used as a control, without any IRDs.

Procedure: The mock-up was covered with a non-uniform layer of wet heavy snow using one articulating snow gun and one fixed-mast snow gun. The bulk of the snow was made Tuesday night before the refrigeration air units had to be defrosted. Once the air units were clear, the room was cooled to 3°F to stabilize the wet snow. The final 1 inch of dry snow was applied to the mock-up early Wednesday morning. Prior to testing, the air units were defrosted and the room cooled to stabilize the new layer of snow before testing.

In the testing phase, the room was increased to 35°F and doors were opened to elevate the temperature of the fins above 32°F. The large fan was used to aggressively circulate the warm air in the room. The discharge of the fan pointed away from the fins to prevent any localized effects, i.e., heating or melting. Room temperature was isothermal at 40°F, and snow slid off the top control fin (B4) when the fin temperature was 39°F. The ice/snow accumulation slid off the control fins once the fin temperature reached 39°F.

When the IRD were removed from the B side of the fins, the metal skin had holes from the attachment screws, and a few holes had an upward dimple around the edge. To prevent the water from getting into the fins, the holes were covered with a 1-inch-diameter patch made from silver tape. During this test we observed that the dimples provide some mechanical locking between the ice/snow accumulation and the fin. In other words, the accumulations would slide off standard fins easier than observed in these tests (see Figures 3.10 and 3.11).

It was obvious that the barrier IRDs (i.e., options 1, 2, and 3) would retain the accumulations on the fins. The question was raised whether the icicles and ice on the lower edge of the fin would fall off if the exposed edges of the fin and IRDs were exposed to solar heating. IRD options 2 and 3 were of particular concern, considering that the exposed metal of the IRD would heat up and melt the adhesion (see Figure 3.12). Radiant heaters were used to simulate solar heating of the edge of the A1 and A2 fins as shown in Figure 3.13. Although the ice melted off the IRDs, the icicles remained anchored to the fin via the ice frozen in the drainage paths under the barriers. In this particular test, the icicles melted in place.

Observations regarding compliance with contract documents:

1. Ice on the control fin (B side) slid off in large sheets.
2. All the IRDs retained the snow.
3. The ice below the continuous barriers melted in place.

Photography from the testing

Figure 3.1. Initial condition of mock-up covered in snow and ice of varying thickness from 2.5 to 7 inches. IRDs are installed on the A, or left, side of the fin. The B, or right, side without the IRDs is used as the control. Fins are in configuration 3, i.e., top three fins are at 50° and the bottom fin is at 30°.

Figure 3.2. Initial condition of the bottom fin 1. IRD option 1 is on the near side (A1) and the control fin (B1) is on the far side.

Figure 3.3. Initial condition of fin 2 with IRD option 2 on the left (A2) and the control (B2) on the right side of the photograph. Note the exposed bottom edge of the IRD that could be deiced by solar heating and subsequent shedding of the icicles.

Figure 3.4. Initial condition of fin 3 with IRD option 3 on the A (left) side and the control on the B (right) side.

Figure 3.5. Initial condition of fin 4 with IRD option 4 on the A or left side (A4) and the control on the B or right side (B4).

Figure 3.6. Cross section of ice that fell off fin B4. Note the layering of ice and snow, typical of a wet snow.

Figure 3.7. Snow sliding off fin B1. Note the size of the snow/ice block and the exposed cross section of the accumulation still on fin A1.

Figure 3.8. Piece of ice that fell off the control fin B3.

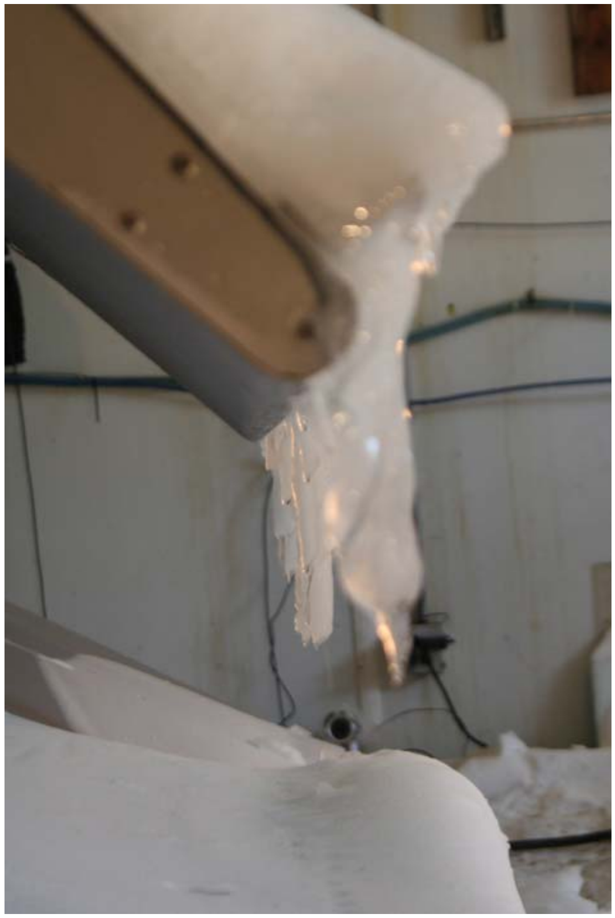

Figure 3.9. Melt water dripping off fin A2 at 50° onto the fin A1 at 30°. The concern was that the bottom fin extended beyond the edge of the upper fins due to the shallower angle. Melt water from the upper fins accumulated on the lower fin resulting in an excessive accumulation on the lower fin. As observed in the previous tests, the drip lines are uphill from the IRD. It was concluded that mixing the fin's slopes does not significantly change the size of the accumulation on the lower fin.

Figure 3.10. Piece of ice from fin B3. Note the scratch in the bottom of the piece that runs from the bottom of the fin on the left toward the top of the fin on the right.

Figure 3.11. The mock-up arrived at CRREL predrilled for the IRDs along the bottom edge of the fins. To minimize the test matrix and compare IRD performance with control fins with similar accumulations, the IRDs were installed on the left or A side of the fin. The attachment holes were covered on the right or B side with 1-inch-diameter patches of foil tape. This particular hole was slightly dimpled, providing a mechanical lock for the snow as evidenced by the scratch in the piece of snow shown in Figure 3.10. The dimple may have impeded the ice shedding process during this study compared to a standard fin, reinforcing the need for IRDs.

Figure 3.12. The question was raised regarding the icicle shedding process if the IRD were exposed to the sun, in particular IRD option 2 installed on fin A2. The exposed metal would conduct the solar heat, melt the anchor points for the ice, and subsequently large icicles could fall.

Figure 3.13. Radiant heaters are directed to the leading edges of fins A1, A2, and, to some extent, A3 to evaluate the effect of solar heating on the ice shedding process.

Figure 3.14. Exposed IRD option 2 on fin A2 following exposure to a radiant heater. The icicles melted before the ice in the drainage path anchoring the icicles started melting. In this particular test, the icicles melted in place.

Figure 3.15. Lower edge of fin A2 and the remaining ice is firmly anchored by the ice in the drainage paths.

Figure 3.16. Condition of fins A3 and A4 after several hours of melting by ambient temperature and radiant heaters.

Figure 3.17. Even after vibrating the fins, the ice remains attached to the outer surface of fin A3 with IRD option 3.

Figure 3.18. Snow mass can be pushed off the end of the fin, providing confidence that the IRDs retain the accumulation in place.

Description of testing procedures and results yielded:

1. Large pieces of snow slid off the control fins (B side).
2. The holes exposed in the control fins by removing the IRDs on the B side provided some mechanical attachment for the accumulation. The minimal mechanical attachment delayed the sliding of the accumulation, reinforcing the need for IRDs.
3. The icicles melted in place on the A fins, but this test was done without wind that could add additional loading on the icicles.

Modifications to fins: No changes were made to the fins or the IRDs.

Appendix D: Test 4

Issue date: May 23, 2008

Project title and number: Evaluation of Sun Control Fins in Snow and Icing Conditions

Testing agency name and address: Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755

Name of test personnel: William Burch, Tommie Hall, and Len Zabilansky

Date of testing: May 15, 2008

Significant meteorological conditions: Mock-up was covered with ice varying in thickness of 3/8 to 1/2 inch. Before testing, a slot between side A and B was deiced to insure that ice shedding off each side was independent.

Report number: Test 4

Mock-up test number: Configuration 1 was on the A or left side of mock-up with ice retention device (IRD) option 1, IRD option 2, IRD option 3, and IRD option 4 installed on fins A1, A2, A3, and A4, respectively, with fin A1 on the bottom. Configuration 4 was on the B or right side of the mock-up with modified IRDs on fins B2 and B3.

Procedure: In the previous tests, the accumulations slid off the fins in large pieces, and test team members concluded this would be unacceptable. Rather than conduct another test to verify the mode of failure, we elected to modify IRD option 2 by increasing the drainage area through the angle to minimize the "rain gutter" on the top edge of the IRD. One modification was to increase the number of 3/8-inch drainage holes by decreasing the spacing to 3 inches on center. This modified IRD will be referenced as option 2b, which was installed on fin B2. The second modification to IRD option 3 was to machine slots ½-inch wide by 2-inch long spaced 3 inches on center. This modification will be referred to as IRD op-

tion 2b, which was installed on fin B3. Because option 4 appeared to be the best IRD, fin B1 was fitted with IRD option 4 at 12 inches on center per the design. This provided the evaluation team the opportunity to assess the performance of IRDs installed on the bottom of a fin stack. Fin B4, which is on the top, was used as the control fin.

The room was cooled to 0°F before beginning the misting cycle that entailed spraying the model and waiting approximately 10 minutes to allow the surface to refreeze. The icing process took approximate 2 ½ hours and was left over night to stabilize.

On May 15 at 6:20 am, the room was warmed up by opening the access doors and the large fan was used to aggressively mix the air; the discharge of the fan was away from the fins to avoid wind loading and localized effect (i.e., heating).

The ice slid off fin B4 (the control fin) at 9:45 am when the thermocouple (TC) on the bottom of the fin (TC 8) measured approximately 39°F. It was typical for the accumulation not to slide off the fin until the temperature on the bottom of the fin was approximately 39°F. The team concluded that the accumulation kept the top surface cold and the interior of the fin had to warm up before there was sufficient melt water under the accumulation to let it slide. The temperature of the snow surface measured with an infrared thermal gun was approximately 28°F just before the accumulation slid off.

Observations regarding compliance with contract documents:

1. Ice on the control fin (B4 side) slid off as large sheet.
2. The drainage paths on all the continuous IRDs (options 1, 2, 3, 3a, and 3b) eventually froze. The continuous barrier served more as a gutter conveying water to the end of the barrier with the potential to form large icicles.
3. On all the IRDs, icicles formed on the leading edge of the fin. This may be of concern because wind could dislodge the icicles before they melt in place.
4. All the IRDs retained the ice and allowed the ice sheet to melt in place.

Photography from the testing

Figure 4.1. IRD option 4 installed on fin B1 before icing.

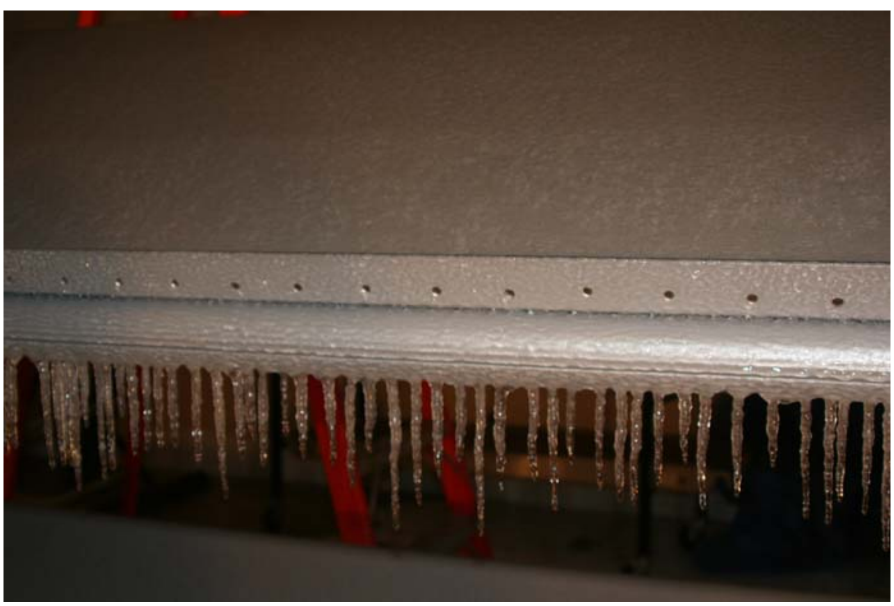

Figure 4.2. Condition of IRD option 3a (3/8-inch drain holes 3 inches on center) on fin B2 after 40 minutes of icing.

Figure 4.3. Condition of IRD option 3b (1/2- x 2-inch slots 3 inches on centers) on fin B3 after 40 minutes of icing.

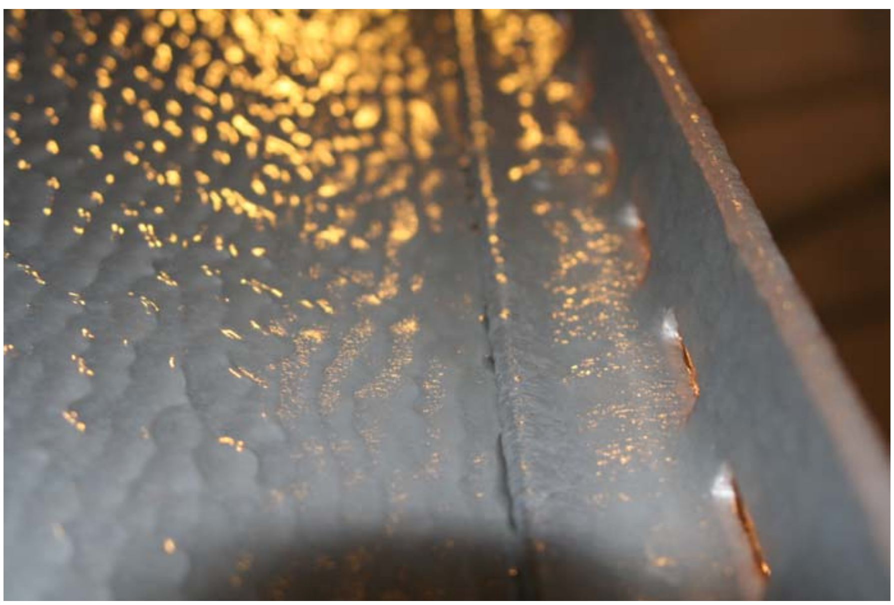

Figure 4.4. Top view of IRD option 3b showing the drainage paths and slots starting to freeze up after 40 minutes of icing.

Figure 4.5. Icing of fin 3 after an hour of icing; option 3 is on the left (A3) and option 3b (B3) is on the right. With both IRDs, drainage paths are freezing. Water is flowing over the top of A3, and the slots in option 3b (B3) are starting to be plugged.

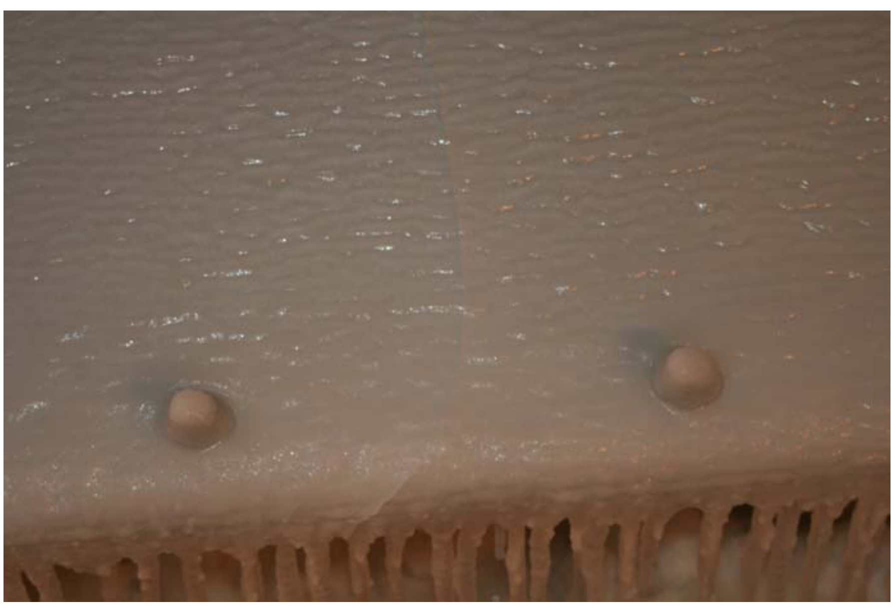

Figure 4.6. Icing conditions of IRD option 4, fin B1, after 70 minutes of icing.

Figure 4.7. Icicles on fins 2 and 3 after 70 minutes of icing. Note the size of the icicles in the center of the fins.

Figure 4.8. The drainage paths are frozen and the water is collecting and freezing behind IRD option 1 on fin A1.

Figure 4.9. Similar to Figure 4.8, the drainage paths are frozen and the continuous barrier of IRD option 2 serves more as a gutter. An icicle is starting to form at the end of the fin.

Figure 4.10. Sufficient water collected behind IRD option 3 to fill the gutter, and water is run over the front surface of the IRD forming icicles on the outer surface.

Figure 4.11. Bottom of fin B3 with IRD option 3. The majority of the icicles are attached to the front skin as the water in flowing over the top barrier as shown in Figure 4.10.

Figure 4.12. Left end of fins A1 and A2 with the larger icicles compared with the interior icicles.

Figure 4.13. Although IRD option 3b had a larger drainage area, given time they would be plugged by ice.

Figure 4.14. Ice accumulation on control fin B4 is cantilevered off the fin 16 inches just before it falls.

Figure 4.15. (Left) Fins on the A side after a couple of hours of warm up with most of the icicles melted. (Right) Fins on the B side with the ice still in place except on the top fin (B4) used as a control. The icicle melted in place on the fins with the IRDs.

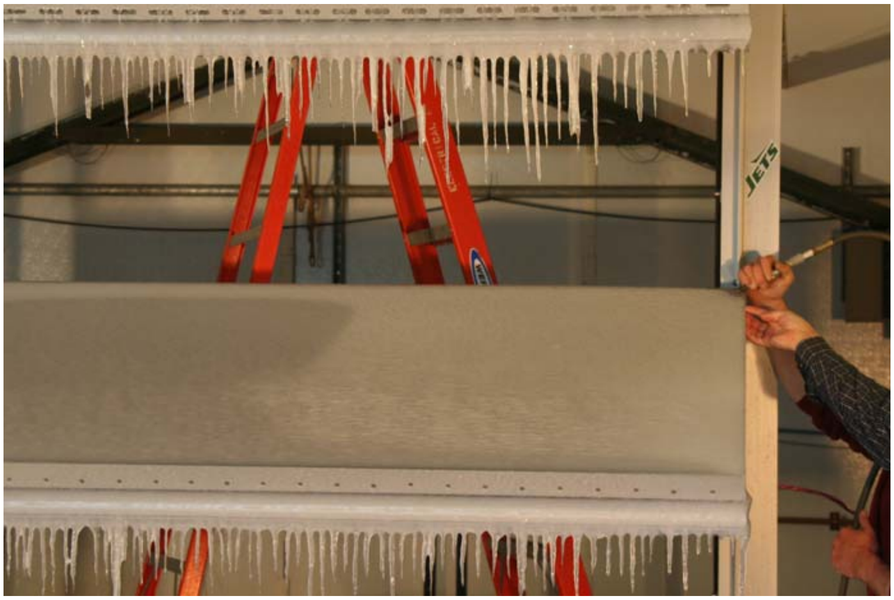

Figure 4.16. Using compressed air to simulate high wind that could lift the ice sheet. The air has displaced the water under the ice in the lighter areas, eliminating the suction provided by the water. The ice sheet could not be lifted off the fin even with the water suction eliminated.

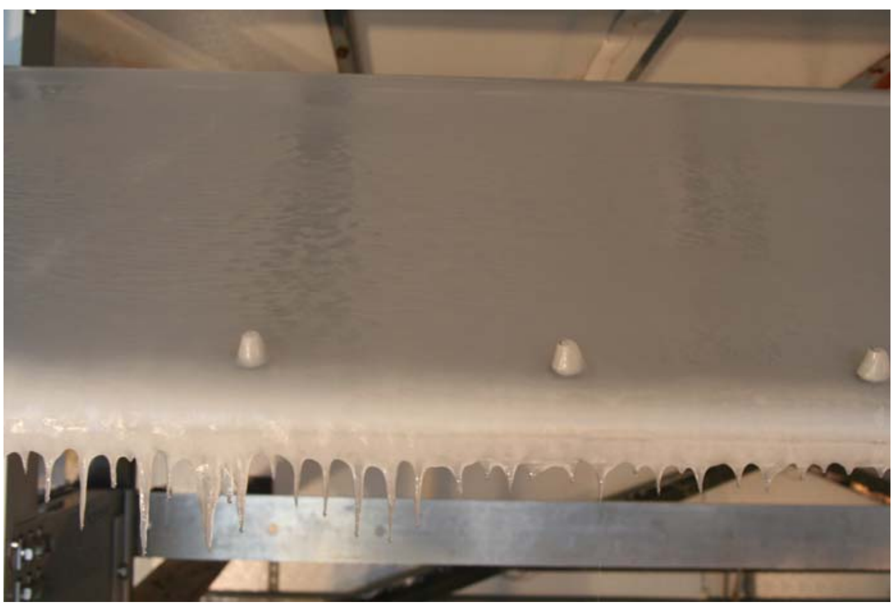

Figure 4.17. Fin A4 at 11:06 am, 2 hours and 21 minutes after the ice slide of fin B4. The ice is melting in place with water on and under the ice sheet.

Figure 4.18. IRD option 4 is spaced off the fin 3/16 inch and the shoulder provides a mechanical lock for the ice sheet to prevent it from being lifted. The light and dark areas indicate that the water is flowing under the ice.

Figure 4.19. The ice around IRD option 4 on fin B1 was melted using a heat gun to verify the simple IRD would arrest sliding ice. Before all the IRDs were melted free, the ice sheet started to slide, reinforcing the recommendation that IRDs are necessary to prevent the ice from sliding off the fin. The IRDs did stop the moving ice sheet.

Figure 4.20. Breaking up the ice on fin A1, so it could slide off the edge of the fin.

Figure 4.21. Ice accumulation from behind IRD options 1 and 2. Given the volume of ice, considerable melting would have to take place before the drainage paths under the IRDs would be open.

Figure 4.22. Similar to IRDs shown in Figure 4.21, the ice behind IRD option 3 also blocks the drainage path under the IRD. The surface on the right side of the ice mirrors the back of the IRD. The broken edges on the top and bottom are from the ice in the drainage path under the IRD and ice over the top of the IRD, respectively. Again, considerable melting would have to take place before the drainage paths would be open; in the meantime, the water would flow to the ends of the fin.

Description of testing procedures and results yielded:

1. The drainage paths on all the continuous IRDs (i.e., options 1, 2, and 3) froze and the top edge of the barrier served as a gutter conveying the water to the end of the IRD. This confirms observations made in previous icing tests.
2. The ice slid off the control fin B4 as a large sheet.
3. IRD options 1, 2, and 3 retained the ice, but could result in large icicles due to the blocked drainage paths.
4. IRD option 4 anchored the ice and allowed the ice to melt in place.
5. When the ice was melted around IRD option 4 on B1 with a heat gun, the ice sheet slid and reengaged with the IRD, and sliding stopped. The test reassured the test team that IRD option 4 did retain the ice, without the problems associated with the frozen drainage paths of the other IRDs.

Modifications: IRD option 3 was modified to increase the size of the drainage area using more holes or slots. Although the modification allowed the water to pass through the IRD, the holes or slots eventually froze and the drainage paths blocked.

Appendix E: Test 5

Issue date: May 23, 2008

Project title and number: Evaluation of Sun Control Fins in Snow and Icing Conditions

Testing agency name and address: Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755

Name of test personnel: William Burch, Tommie Hall, and Len Zabilansky

Date of testing: May 15–19, 2008

Significant meteorological conditions: Mock-up was covered with ice varying in thickness from 3/8 to 1/2 inch. Before testing, a slot between side A and side B was deiced to insure that ice shedding processes were independent.

Report number: Test 5

Mock-up test number: Configuration 1 was on the A or left side of mock-up with ice retention device (IRD) option 4 installed on all the fins. On fin A2, the IRDs were installed upside down to assess if the upside down cone would have better capture efficiencies. The B side was set to configuration 4 without any IRD.

Procedure: In the previous tests, the continuous IRD were very problematic because the drainage paths froze and the upper edge of the device served as a gutter. With the drainage paths plugged, the water had two options:

1. Flow to the end of the fin via the “gutter” and potentially form a large icicle. Because of the narrow clearance between adjacent fins, and considering that the fins were stacked, it is conceivable that an ice column could freeze in the vertical gap between adjacent fins in the stack.

2. Once the gutter behind the barrier filled with ice, the water would flow over the barrier and form large icicles on the leading edge of the fin. The panel seam on the front edge and the ice in the drainage paths provided the icicles' only anchoring, and it may not be sufficient to withstand windy conditions.

Given these problems, IRD options 1, 2, and 3 were not considered as viable options. Option 4 retained the ice and snow and allowed it to melt in place. The test team elected to use Test 5 to compare the performance of IRD option 4 with standard fins. All the fins on the A side of the mock-up were fitted with IRD option 4 at 12 inches on center per design. The IRDs installed on fin A2 were turned upside down to assess whether the upward taper would improve the capture efficiencies of the discrete IRDs. The B side of the mock-up was used as the control without any IRDs.

The model was covered with 3/8 to ½ inch of ice by cycling between misting and allowing 10 to 15 minutes for the surface to refreeze. During the 4 hours it took to ice the model, the ice temperature dropped from 3°F to -6°F. Once the icing process was complete, the set point for room temperature was increased to 20°F to allow the room to warm up while the ice was stabilizing.

Test 5 included three phases: localized heating, continuous heating of upper fins with refreezing of melt water on lower fins, and allowing the ice to melt in place. In the first phase, infrared heaters were used to evaluate the impact of the upper fins being heated by solar radiation, building exhaust, etc. This caused localized melting, and the melt water dripped onto the lower fins and refroze. To simulate the solar radiation, two 5-foot-high 13-kW infrared heaters were set on 6-foot scaffolding, approximately 9 feet from fins A3 and A4. The temperature at the mock-up varied between 32°F and 35°F. The lower fins, A1 and A2, were shielded from the heaters by a plywood panel. A solar cycle was simulated by turning the heater on for approximately 15 minutes to melt the ice and get dripping off the icicles, followed by 10 minutes of the heaters being off to allow the melt water to refreeze. The temperature of the room was roughly 22°F during this phase of the test. After seven cycles the heaters were turned off for 1 hour.

In the second phase, the heaters were moved away from the mock-up such that infrared heaters could run continuously and melt only the ice on fins A3 and A4. The heaters were run continuously for the next 6 hours to melt

the ice on the upper fins and allow the melt water to refreeze on the lower fins.

The room was maintained at 20°F over the weekend. On Monday morning the refrigeration system was shut off and the access doors opened to warm the room to above 32°F to allow the ice to melt in place.

The ice slid off the fins on the B side in large sheets as observed in the previous test. The ice on the A side melted in place, including the large accumulations created earlier by the "solar heating."

Although the discrete IRD option 4 was the most simple, it provided sufficient ice retention in all the scenarios tested. The remaining issue is the formation of icicles, which will have to be monitored and physically removed if they become a hazard.

Observations regarding compliance with contract documents:

1. Ice on the control fin (B4 side) slid off as a large sheet as observed in previous test.
2. IRD option 4 did stabilize the ice accumulation and allowed it to melt in place.
3. In this particular test with ice, there was no significant difference in the capture efficiencies between the normal conical profile versus the inverted cone shape of IRD option 4.
4. The localized heating created large ice accumulation and icicles on the fins in the shadows.
5. The panel joint on the leading edge of the fin provided a mechanical attachment point that stabilized the icicles, but it could be marginal if combined with high wind.

Photography from the testing

Figure 5.1. IRD option 4 installed on all the fins on the A side. The IRDs are inverted on fin A2 as shown in Figure 5.3.

Figure 5.2. B side of the mock-up with no IRDs installed and the attachment hole covered with foil tape disc.

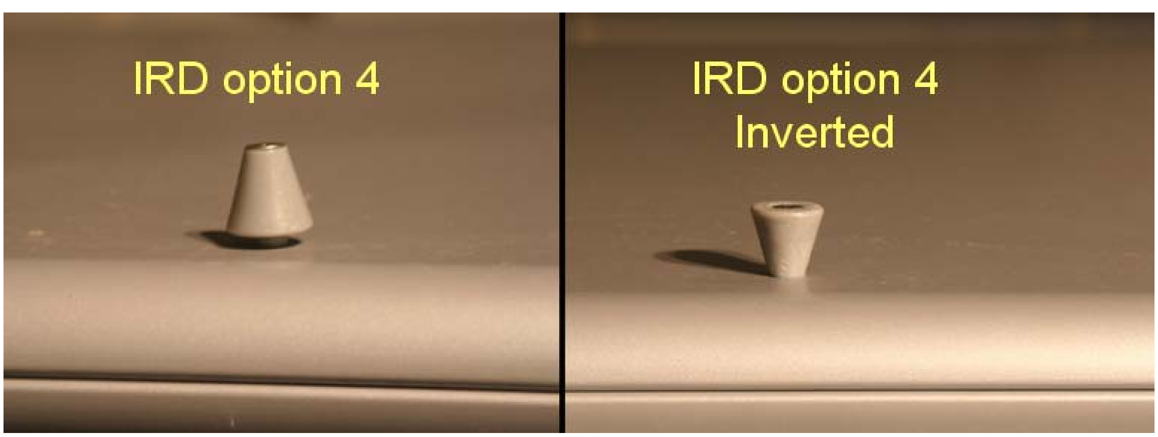

Figure 5.3. IRD option 4 as designed on the left and the inverted option on the right.

Figure 5.4 Initial condition of fins 2 and 3 while a slot between the A and B sides is being deiced with a hot iron.

Figure 5.5. Initial condition of fin A1.

Figure 5.6.Initial condition of fin A2.

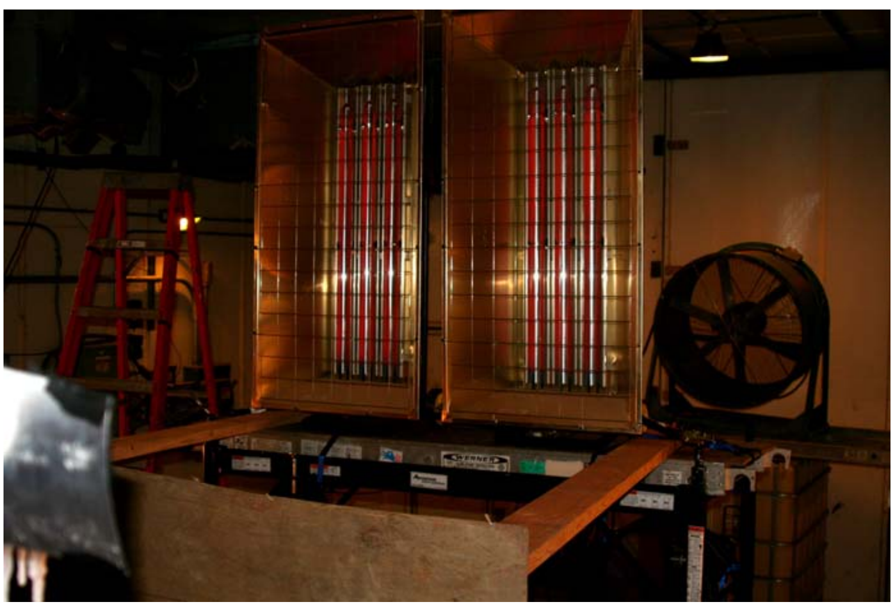

Figure 5.7. The two 13-KW infrared heaters mounted on 6-foot scaffolding to simulate solar heating of fins A3 and A4. A plywood panel in the foreground is used to shield fins A1 and A2 from the heaters.

Figure 5.8. Condition of fin A1 following seven solar cycles.

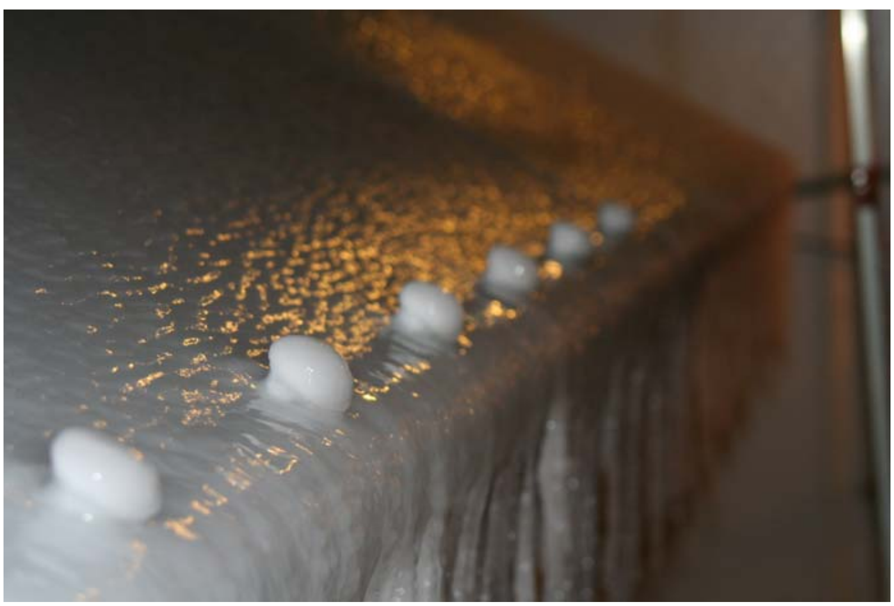

Figure 5.9. Condition of fin A2 following seven solar cycles.

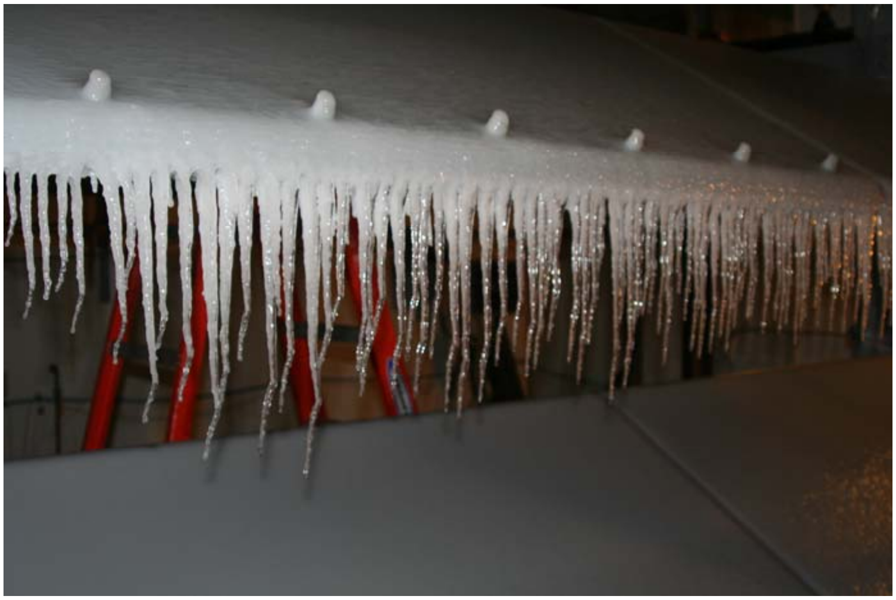

Figure 5.10. Condition of fin A3 following seven solar cycles.

Figure 5.11. Condition of fin A4 following seven solar cycles.

Figure 5.12. Condition of fin A1 after the infrared heaters were on for 5 hours with the room at approximately 23°F.

Figure 5.13. Condition of fin A2 at the same time as fin A1 shown in Figure 5.10. The melt water from fins A3 and A4 refroze on fin A2.

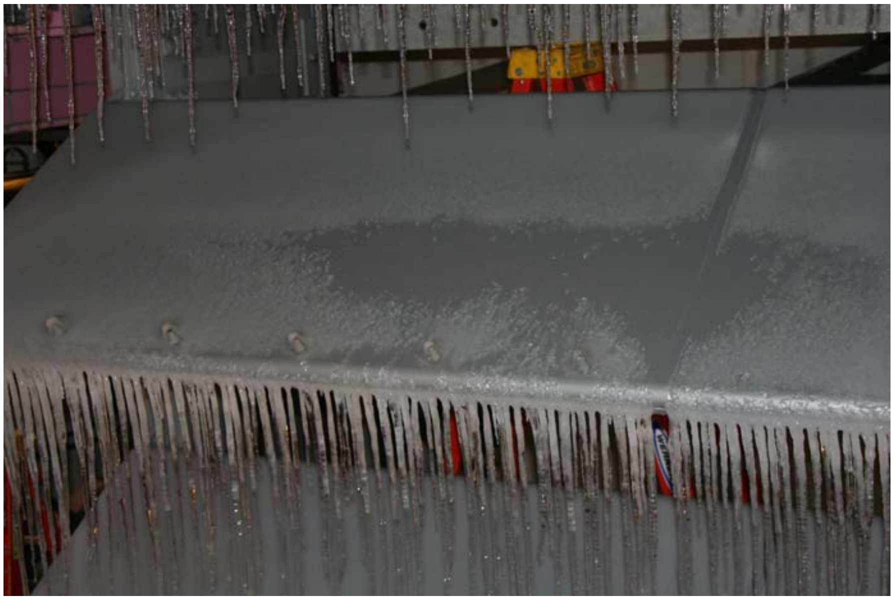

Figure 5.14. Condition of fin A3 at the same time as fin A1 shown in Figure 5.10. Note the deiced section of the fin.

Figure 5.15. Condition of fin A4 at the same time as fin A1 shown in Figure 5.10.

Figure 5.16. Close-up of the leading edge of fin A4 shown in Figure 5.13. The panel joint is providing mechanical anchoring for the icicles.

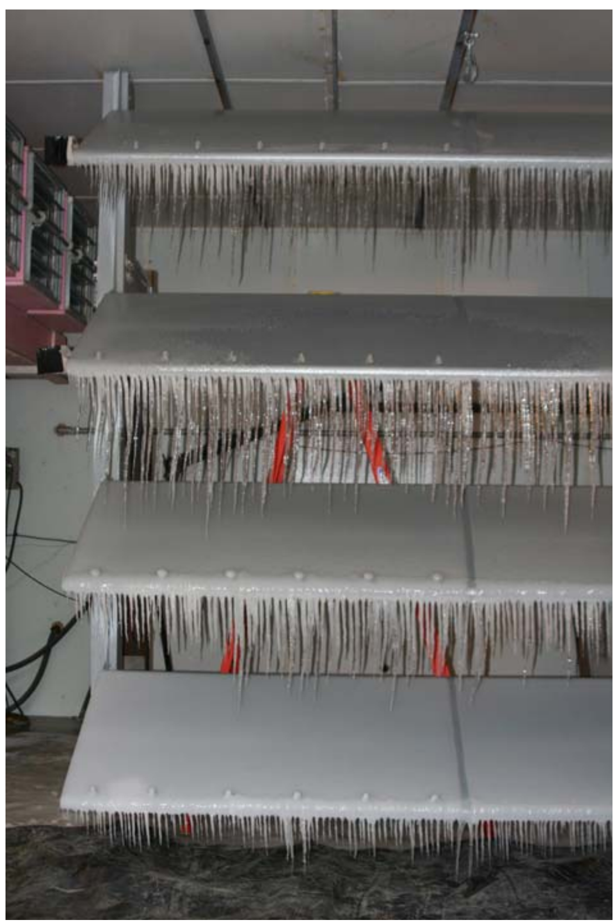

Figure 5.17. Condition of the A fins after the weekend at 23°F.

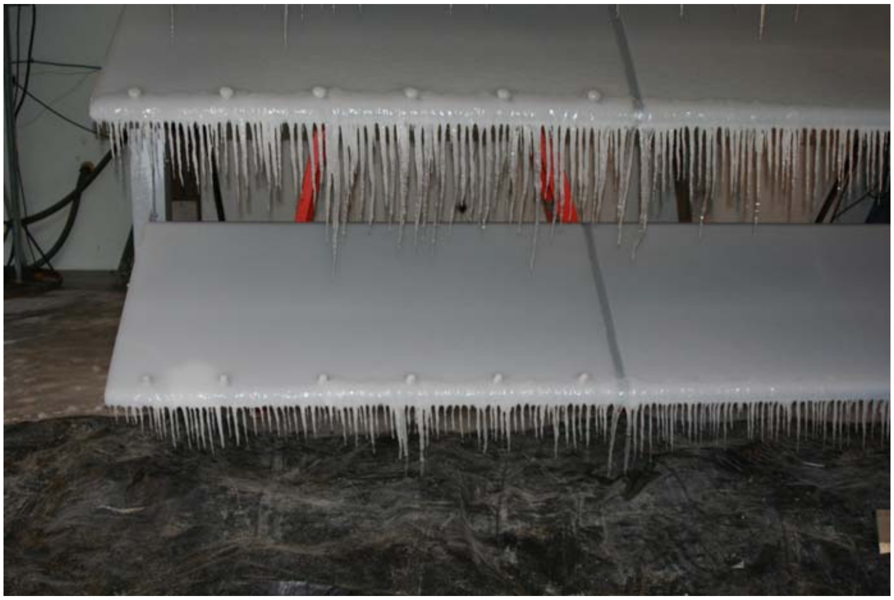

Figure 5.18. Close-up of fins A1 and A2. The bulk of the melt water from fins A3 and A4 refroze on fin A2.

Figure 5.19. Close-up of fins A3 and A4; note the long thin icicles.

Figure 5.20. Fins on the B side; the radiant heaters on fins A3 and A4 did cause melting on fins B3 and B4.

Figure 5.21. Close-up of fins B1 and B2.

Figure 5.22. Fins B2, B3, and B4. Note the size of the icicles on the A side that was heated with the infrared heaters compared to the right side outside the range of the heaters.

Figure 5.23. Icicle removed from fin B2. The ice mirrors the smooth face of the fin with a ridge as evidence of the mechanical attachment in the panel joint.

Figure 5.24. Ice sliding off fin B. Ice on the leading edge was melted by the infrared heaters used in the previous testing phase.

Figure 5.25. Ice sheet is cantilevered off fin B3 approximately 14 inches before it finally breaks along the edge of the fin.

Figure 5.26. Fin A1 after a day of melting with just the IRD option 4 protruding through the ice accumulation.

Figure 5.27. Condition of fin A2 after a day of melting with the inverted IRD option 4 protruding through the cover.

Description of testing procedures and results yielded:

1. The ice on the A side was retained and allowed to melt in place using the IRD option 4 as compared to the B side where the ice freely slid off in large sheets.
2. Localized heating melted the ice on the upper fins resulting in ice accumulation on the lower fins. The IRDs on the A side retained all the ice while it melted in place.
3. The panel joint in the front of the fin provided some mechanical attachment for the icicles, but this may not be sufficient anchoring in a high-wind event.
4. Inverting IRD option 4 did not have any apparent advantage in retaining or arresting ice.

Modifications: IRD option 4 was inverted on fin A4.

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14. ABSTRACT
Ice and snow accumulation sliding from the exterior wall fins installed on the New Meadowlands Stadium in New Jersey, future home field for the New York Jets and New York Giants football teams, was recognized as a potential hazard to pedestrians. The objective of this test program was first to determine if the hazard existed with the standard fin and secondly to evaluate the performance of four ice retention devices (IRDs). A mock-up was assembled using four fins in a vertical stack with different angles. Four IRDs were tested: three were continuous strips and the fourth was a truncated cone attached to the fin at 12 inches on centers. The IRDs were mounted along the lower edge of the fin. To provide water drainage, all the IRDs were spaced off the fin using 3/16-inch plastic spacers. To assess the effectiveness of the IRDs under similar conditions, IRDs were only installed on the fins on the left side of the mock-up while the right side, or standard fin, was used as a control.

Testing confirmed that IRDs are needed to reduce the potential hazard of large sheets of snow and ice sliding off the fin. The continuous barriers are problematic because the drainage paths freeze and water travels to the end of the fin to form large ice columns or because water travels over the top of the barrier to form icicles with limited anchoring. The fourth option, the truncated cone, provides discrete anchoring for the accumulation and allows it to melt in place. The potential for large icicles to form still exists; when they present a hazard to pedestrians they should be physically removed.

15. SUBJECT TERMS
accumulations, falling ice, ice, ice control, ice retention, shedding, snow, structures

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